The principal organs of the respiratory system are the two lungs, which are in the right and left sides of the chest (thoracic cavity) and are separated from each other by the heart. Air passes into and out of the lungs through a series of passages and tubes called the upper airways. The flow of air depends on other organs, including the muscular diaphragm and the muscles and bones that make up the wall of the thoracic cavity (Fig. 5.1).

Part of each lung consists of tubes called the lower airways; they end in the microscopic sac-like alveoli, which make up most of the lungs. The lower airways transport air to and from the alveoli. Many pulmonary vessels transport blood throughout the lungs.

MAIN FUNCTIONS FOR HOMEOSTASIS

Working in a coordinated fashion controlled mostly by the nervous system, these structures perform the two functions of the respiratory system: gas exchange and sound production. Gas exchange involves two processes: obtaining oxygen and eliminating carbon dioxide.

Gas Exchange

The respiratory system obtains oxygen by providing conditions that allow the oxygen contained in air to pass into the blood flowing through the lungs. The circulatory system then transports the oxygen throughout the body. Oxygen (O₂) must be supplied to body cells because it is a raw material used by mitochondria to obtain energy from nutrients. This energy provides the power needed to perform all essential bodily activities.

The respiratory system eliminates carbon dioxide (CO₂) by providing conditions that allow it to move out of the blood in pulmonary vessels and into the atmosphere. Carbon dioxide is transported from body cells to the lungs by the circulatory system.

Carbon dioxide must be eliminated because it is a waste product from the series of chemical reactions in mitochondria that release energy from nutrients. When CO₂ accumulates within the body, it can interfere with body functions because CO₂ combines with water to produce carbonic acid. The excess carbonic acid upsets the acid/base balance of the body. This disturbance can alter body proteins. Body structures and functions
can be adversely affected, and serious illness or death can follow. Still, some acidic materials must be present for the body to achieve a normal acid/base balance, and a deficiency in acids can be as disastrous as an excess. Furthermore, some CO\(_2\) in the blood is used to make a buffer. Therefore, the respiratory system must eliminate some but not too much CO\(_2\).

Many other acidic materials in the body contribute to the acidic side of the acid/base balance. If there is an increase in acidic substances other than CO\(_2\), the respiratory system can help maintain acid/base balance by eliminating more CO\(_2\). This occurs in individuals whose kidneys do not eliminate acids adequately.

The rate of bodily activities changes from time to time. These changes cause fluctuations in the rates of O\(_2\) use and CO\(_2\) production and the amount of other acids. To maintain homeostasis, negative feedback systems employing the nervous system normally ensure that the rate of gas exchange by the respiratory system increases or decreases to meet these fluctuations. This adaptive mechanism occurs when a person begins to breathe more heavily soon after beginning vigorous physical activity.

The maximum amount that gas exchange can be increased to compensate for increases in bodily activity constitutes the reserve capacity of the respiratory system. The limited nature of respiratory capacity seems to contribute to setting a maximum limit on how vigorously a person can exercise. This limit is experienced as the sensation of feeling completely out of breath while exercising. Limitations in the maximum functional capacities of the circulatory, nervous, and muscle systems may also play a role in establishing the maximum rate of physical activity attainable.

Three operations are involved in carrying out gas exchange. Ventilation (breathing) involves moving air through the airways into and out of the lungs. Perfusion of the lungs involves the
movement of blood through the pulmonary vessels. Diffusion causes the O₂ in inhaled air to move into the blood while CO₂ exits into the air in the lungs.

### Sound Production

Sound production, which is the second main function of the respiratory system, is important because it helps people communicate. A short section on sound production, including the effects caused by aging, is presented at the end of this chapter.

### VENTILATION

Ventilation involves two phases: inhaling (inspiration) and exhaling (expiration). Inspiration moves air into the nostrils and down the airways to the deepest parts of the lungs, where the O₂ it contains can diffuse into the blood. Expiration moves air containing CO₂ from the innermost parts of the lungs up and out of the body.

To understand how ventilation occurs, one must realize that air around the body is under atmospheric pressure. Materials normally move from areas of higher concentration or pressure to areas of lower concentration or pressure. For example, air moves into a balloon and inflates it when more air pressure is applied to its opening than is already in the balloon. Conversely, releasing the opening of an inflated balloon results in air rushing out because the pressure within the balloon is higher than atmospheric pressure.

#### Inspiration

Inspiration occurs for the same reason that a balloon becomes inflated. Air moves into the body when the air pressure outside the body is greater than that inside the respiratory system. A person creates this difference in pressure by contracting muscles to move the floor or walls of the thoracic cavity.

The floor of the thoracic cavity consists of the dome-shaped diaphragm, a thick sheet whose edge is muscle and whose center is fibrous material. The muscular edge slants downward sharply and is attached around its perimeter to the body wall. When the muscle contracts, the rounded central region is pulled downward within the body wall, moving like a piston downward in a cylinder. When the central region is pulled downward and the diaphragm flattens somewhat, the pressure within the thoracic cavity decreases. Because moisture on the outer surface of the lungs causes them, in effect, to adhere to the diaphragm, a similar decrease in pressure occurs within the lungs. Since the pressure in the lungs is then lower than atmospheric pressure, air flows through the airways and into the lungs, resulting in inspiration (Fig. 5.2).

The walls of the thoracic cavity contain many bones, including the ribs, the sternum, and some vertebrae. The cartilage and joints that connect these bones allow them to move somewhat when the muscles attached to the bones contract. When
muscles move the ribs and sternum upward and outward, pressure in the thoracic cavity decreases. The lungs, whose surfaces are stuck to the thoracic walls by fluid, also have a decrease in internal pressure, and inspiration occurs.

Inspiration usually involves simultaneous movement of both the diaphragm and the bones of the thorax. Some individuals rely mostly on movement of the diaphragm (diaphragmatic breathing), while in others movement of the ribs (costal breathing) makes the major contribution. Inspiration ends when parts of the body stop moving and enough air has come in to raise the pressure in the lungs to atmospheric pressure. If the muscles are held in this position, no further air movement occurs and the lungs remain inflated. People in this state are truly holding their breath.

Inspiration is called an active process because it requires the use of energy. Obtaining this energy uses some of the oxygen that inspiration helps obtain. The energy expended and the oxygen used are called the work of breathing. Usually not more than 5 percent of the oxygen brought in by inspiration is consumed in this process; the rest is available for use by other body cells. Since diaphragmatic breathing is more efficient and requires less energy than does costal breathing, it consumes less oxygen. These differences leave more of the oxygen obtained from inspiration for use by other body cells.

Expiration

Expiration for a person who is resting and breathing quietly normally requires no muscle contraction because the movements of inspiration set up conditions that allow it to occur automatically. For example, when the diaphragm moves downward, it pushes on the organs below it in the abdominal cavity, and this increases the pressure in the abdominal cavity. Also, the movements of the ribs and sternum stretch and bend elastic and springy structures in the thoracic wall such as ligaments, cartilage, and the ribs themselves. Finally, the lungs, which are elastic, are stretched outward.

As a result, as soon as the muscles of inspiration relax, the abdominal organs, structures in the thoracic wall, and the lungs start to spring back to their original positions. This elastic recoil increases the pressure in the lungs. The pressure quickly rises above atmospheric pressure, and expiration occurs. The process is similar to what happens when the opening of an inflated balloon is released. Each expiration is followed shortly by the next inspiration (Fig. 5.3).

Since normal quiet expiration requires no muscle contraction or energy, it is called a passive process. However, when a person becomes very active, passive expiration occurs too slowly to meet the needs of the body. Then respiratory muscles and energy can be used to perform active forced expiration. For example, abdominal muscles can squeeze on the abdominal organs, causing them to push upward on the diaphragm more forcefully, and chest muscles can pull the ribs downward. The resulting increase in pressure in the lungs pushes air out of the respiratory system quickly (Fig. 5.4).

Rate of Ventilation (Minute Volume)

Ventilation usually occurs continuously to provide ongoing replacement of the O₂ being consumed and elimination of the CO₂ being produced. The rate of ventilation must be high enough to maintain homeostatic levels of these gases in the body. The rate of ventilation is called the respiratory minute volume, the volume of air inspired per breath times the number of breaths per minute. The number of breaths per minute is called the respiratory rate. Minute volume can be expressed mathematically:

\[
\text{Minute volume} = \text{volume per breath} \times \text{breaths per minute}
\]

Lung Volumes The volume of air inspired equals the amount of air expired. When a person is at rest and breathing quietly, this volume is called the tidal volume (TV).

When a person is active and has to exchange gases more quickly, inspiratory and expiratory volumes can be increased considerably by increasing the distance the respiratory muscles contract. The extra amount a person can inspire is called the inspiratory reserve volume (IRV); the extra amount a person can expire is called the expiratory reserve volume (ERV). The combination of tidal volume, inspiratory reserve volume, and expiratory reserve volume is called the vital capacity (VC). Vital capacity is the most air a person can expire after taking the deepest possible inspi-
FIGURE 5.3 Passive expiration: (a) Elastic recoil collapses chest partially, causing expiration. (b) Elastic recoil collapses balloon, forcing air out.

FIGURE 5.4 Forced expiration: (a) Muscle contractions and elastic recoil collapse chest partially, causing rapid expiration. (b) Pressure from hands and elastic recoil collapse balloon, forcing air out rapidly.

This can be expressed mathematically:

\[ \text{TV} + \text{IRV} + \text{ERV} = \text{VC} \]

Besides increasing the volume of air respired with each breath, a person can increase the speed at which the air flows. This is accomplished by increasing the speed and force of respiratory muscle contractions, which can magnify pressure changes in the lungs more than 25-fold.

A person who expires as much as possible still has some air left in the lungs. This volume is called the residual volume (RV). Thus, the total amount of air the lungs can hold equals TV + IRV + ERV +
RV and is called total lung capacity (TLC). A small amount of the TLC does not reach the alveoli but remains in the lower airways. This volume of air—the dead space—cannot be used for gas exchange because only the alveoli are thin enough for this process to occur.

**Respiratory Rate** A normal person may have a respiratory rate of 15 to 20 breaths per minute, but this rate can change as needed. If the volume per breath remains high, an increase in the rate of respiration increases the minute volume and therefore the rate of gas exchange. Decreases in the respiratory rate have the opposite effect on the minute volume and the rate of gas exchange. Such adjustments in the respiratory rate occur as changes in bodily activity alter the need for gas exchange.

When the rate of respiration increases, there is less time for each inspiration and expiration. If a person does not increase the rate of airflow, breathing becomes rapid but shallow. Such breathing delivers little fresh air to the lungs for gas exchange.

**REQUIREMENTS FOR VENTILATION**

The major features necessary for proper ventilation include (1) open airways for easy air movement, (2) defense mechanisms that assure that only clean, moist, warm air reaches the lungs, (3) proper pressure changes in the thoracic cavity and lungs to make the air move, (4) compliance in thoracic and lung components so that pressure changes cause them to expand easily to accept incoming air, and (5) control systems that ensure that the process occurs successfully and at the correct rate.

**Contributions by Airways**

The contributions made by muscles and skeletal components to the first four of these requirements were described previously. We will now consider the ways by which the airways contribute to these requirements.

**Nasal Cavities** Inspired air entering the nostrils passes through the nasal cavities above the hard palate. These cavities are held open by the bones of the skull. As air passes through the nasal cavities, it is cleaned, moistened, warmed, and monitored so that it does not harm the delicate structures deep within the lungs (Fig. 5.5).

The air is cleaned because dust and other particles are trapped by hairs inside the nostrils and by the sticky mucus that coats the inside of the cavities. Microscopic hairlike cilia on the cells lining the cavities wave back and forth, causing the mucus to glide back toward the throat. Then the mucus and its trapped debris can be harmlessly swallowed.

The air is moistened by the mucus to prevent drying of the lungs. Heat from the blood in the walls of airways warms the air so that the lungs are not chilled. Finally, sensory nerve cells monitor the chemical contents of the air and send impulses to the brain. The presence of such chemicals is perceived as aromas. The nervous system may cause inspiration to slow or stop if harmful chemicals or particles are detected. Forced expiration (e.g., sneezing) may be initiated in an attempt to blow the noxious materials out of the respiratory system.

A person may inspire some or all of the air he or she breathes through the mouth rather than through the nasal passages. This can increase the rate of airflow, but it reduces the amount of cleaning, moistening, and warming of inspired air. Injury to the airways below the pharynx may result. Inspiring through the mouth can also lead to excessive dryness of the oral cavity, which may cause oral discomfort and sores.

**Nasopharynx** Air in the nasal cavities moves backward into the nasopharynx, which is above the soft palate. Bones and other firm tissues keep this passage open except when one is swallowing, during which the tongue pushes upward on the soft palate. The mucus, cilia, and blood in the nasopharynx further clean, moisten, and warm the air.

**Pharynx** After passing through the nasopharynx, the air moves through the throat, or pharynx, into the opening in the voice box, or larynx. This opening is called the glottis. The pharynx is held open by the firmness of the muscles and other tissues that make up its walls.

Since food and beverages in the oral cavity that are being swallowed also pass through the pharynx, these materials can lodge in the pharynx or enter the glottis, blocking or injuring the airways.
Figure 5.5 Respiratory passages in the head and neck.

Two reflexes controlled by the nervous system prevent these problems.

The *swallowing reflex* occurs whenever solids or liquids are present in the pharynx behind the tongue. This reflex clears the pharynx by pushing materials down into the esophagus. At the same time, a flap called the *epiglottis* is moved over the glottis to prevent materials from entering the larynx. The epiglottis is moved off the glottis after swallowing has been completed so that ventilation can begin again (Fig. 5.6).

The *gag reflex* is caused when irritating materials enter the pharynx. This reflex causes muscles near the pharynx to close the openings into the larynx and esophagus. At the same time, muscle contractions in the abdomen raise the pressure in the esophagus and trachea to prevent materials from entering those passageways. A very strong gag reflex can result in vomiting.

**Larynx, Trachea, and Primary Bronchi** Air passing through the glottis moves through the larynx, down the windpipe (trachea), and through the two *primary bronchi* into the lower airways in the lungs. Plates and rings of springy cartilage within the walls of these airways provide support so that the airways stay open during ventilation.

Materials other than air that enter these air passages initiate the *cough reflex*. During coughing, bursts of air that are expired rapidly force foreign materials up and out of these airways.

The mucus, the cilia, and blood flow in these structures carry out further cleaning, moistening, and warming of the air. The cilia beat in an upward direction so that the mucus glides into the pharynx. Since the mucus carrying materials slides upward in a smooth continuous stream, this mechanism is called the *mucociliary escalator*. Phagocytic macrophages and immune system
FIGURE 5.6 The swallowing reflex: (a) Tongue pushes food back. (b) Soft palate elevates and epiglottis lowers to close airways. (c) Muscle contractions push food into esophagus. (d) Wave of contraction pushes food down to stomach.
cells in the trachea and primary bronchi provide additional defense against foreign materials.

Smaller Bronchi, Bronchioles, and Alveolar Ducts As each primary bronchus enters a lung, it branches repeatedly, forming ever more numerous smaller bronchi and bronchioles and finally microscopic alveolar ducts. The walls of these airways become thinner as they branch and narrow. Cartilage in the smaller bronchi keeps them open during inspiration. There is no cartilage in the bronchioles or smaller airways. A peculiar helical structure of the collagen that coils around the airways and elastin fibers also support these smaller airways. The cartilage and fibers provide the lungs with compliance. Like the trachea and bronchi, these smaller airways are protected by the cough reflex and defense cells and condition the entering air.

Smooth muscle cells in the airway walls allow for appropriate adjustments in their diameter as the amount of ventilation needed fluctuates. The smaller airways provide most of this adaptability. The activity of the muscle is controlled by the nervous system, the endocrine system, and nearby chemicals.

As air is expired and the lungs decrease in size, the open passages in the airways become narrower. The walls of the smallest airways are so thin and weak that these airways close completely before all the air has escaped from the alveoli below them. This air remaining in the alveoli makes up part of the residual volume.

Alveolar Sacs and Alveoli The inspired air in the alveolar ducts passes into blind cup-shaped outpocketings called alveoli. Most alveoli occur in clusters extending outward from slightly enlarged spaces at the ends of the alveolar ducts called alveolar sacs. Each cluster may look like a tightly packed bunch of plump grapes (Fig. 5.7).

There are about 300 million alveoli in the lungs. Because alveoli are hollow, filled with air, and very small and because they make up most of the lungs, dried lungs have the consistency of Styrofoam. The alveoli provide an amount of surface area equivalent to that of an area 30 feet long and 25 feet wide. The walls of the alveoli are very thin, allowing diffusion of O₂ and CO₂ between the air and the blood to occur easily.

Special cells in the alveoli secrete a material called surfactant. As surfactant spreads out, it coats the inner surface of the alveoli and parts of the smaller airways. The surfactant greatly increases the compliance of the lungs by reducing the attraction between the water molecules on the inner surfaces of the lungs. Without surfactant, the attraction (surface tension) would be so great that the alveoli and small airways would collapse. The inner surfaces would stick together tightly, making it nearly impossible for them to separate and fill with air during inspiration. These characteristics can be compared to the difference between the effort needed to inflate a new balloon that contains a powdery surfactant and the effort needed to inflate an old balloon that dried after becoming damp.

Surface tension is important because as it makes the lungs collapse, it helps increase the pressure in the lungs and therefore assists in expiration. The combination of a moderate amount of surface tension in the alveoli and the large surface area they provide makes expiration much easier.

Control Systems

Nervous System Ventilation begins with inspiration, which requires the contraction of muscles. The nervous system signals activating these muscles originate in a region of the brain called the medulla oblongata and travel to the muscles through nerves. The medulla oblongata is inside the region of the skull just above the neck. The part of it concerned with respiration is called the respiratory control center.

The respiratory control center starts inspiration when it detects an increase in CO₂ levels or a decrease in O₂ levels in the blood flowing through it. When sensory nerve cells from the aorta and arteries in the neck detect very high levels of CO₂ or very low levels of O₂, these nerve cells also stimulate the respiratory control center. Other sensory neurons in the lungs send impulses to the respiratory control center, telling it that the lungs are in a partially collapsed condition and are ready for inspiration. Sensory nerves from muscles and joints inform the respiratory center when a person begins physical activity and will need more gas exchange.

Nerves from the lungs inform the respiratory center and a nearby part of the brain called the pons when inspiration is complete. The brain then
FIGURE 5.7 Lower airways and alveoli.
stops the impulses for inspiration. As the muscles relax, expiration begins because of elastic recoil of the thorax and lungs. The respiratory center can also send impulses to the muscles indicating that a forceful expiration is needed.

The respiratory center and the pons monitor their own impulses and are also informed by nerves from the lungs when expiration is complete. This triggers the beginning of the next inspiration. Therefore, the linking and repeating of two negative feedback systems result in rhythmic breathing.

The depth of breathing, the speed of airflow, and the respiratory rate are adjusted when the respiratory center detects that CO₂ or O₂ concentrations and the acid/base balance in the blood are beginning to wander from proper levels. The adjustments restore appropriate gas levels and acid/base balance so that homeostasis is maintained.

Ventilation is also modified by the swallowing, gag, and cough reflexes. In addition, upper regions of the brain such as the areas controlling emotions and those controlling conscious actions can influence the respiratory center. The conscious control areas allow a person to voluntarily inspire, expire, stop ventilation, or modify ventilation for actions such as talking.

The nervous system also controls ventilation by adjusting the size of the lower airways. Impulses from the sympathetic nervous system cause relaxation of smooth muscles in the airways, permitting them to dilate and increasing minute volume. Parasympathetic nerves cause the smooth muscles to contract, constricting the airways and reducing minute volume. These changes allow the rate of gas exchange to maintain homeostasis for O₂ and CO₂.

Endocrine System  Hormones from the endocrine system also help regulate ventilation. Norepinephrine makes a main contribution. This hormone has the same effect on the airways as do impulses from sympathetic nerves.

**AGE CHANGES AFFECTING VENTILATION**

Because everyone’s airways are subjected to some air pollution and other environmental insults, it is difficult to know which age-related changes in airways are due to aging and which are due to other factors. However, certain changes seem to occur in all people. These universal changes are considered age changes and thus are included in this section. Let us examine how age changes affect the five requirements for ventilation.

**Open Airways**

**Mucus and Cilia**  All airways from the nasal cavities to the smallest bronchioles produce mucus continuously. With aging, the mucus produced is more viscous and therefore more difficult to move. In addition, both the number and the rate of motion of the cilia decrease. As the clearing out of mucus slows, the accumulation of mucus narrows airways, and this inhibits ventilation. When ventilation becomes more difficult, the work of breathing increases and extra CO₂ is produced by the muscles of ventilation, making respiration less efficient. Narrower airways also reduce the rate of airflow and therefore reduce the maximum possible minute volume.

**Airway Structure**  Age changes in the walls of bronchioles cause them to become even narrower, amplifying the effect of mucus accumulation. In addition, the bronchioles close earlier during expiration, trapping more air in the smaller airways and in the alveoli, especially in the lower parts of the lung. One result is an increase in residual air. This causes the fresh air entering with each inspiration to be mixed with a larger amount of stale residual air, decreasing the rate of diffusion. A second result is uneven lung ventilation.

While the bronchioles become narrower, the larger airways in the lungs and the alveolar ducts increase in diameter. These changes compound the negative effects by increasing the dead space. Thus, fresh inspired air is mixed not only with more residual air in the smallest airways and alveoli but also with more dead space air. This further decreases the rate of diffusion.

The increase in tidal volume with age may help minimize the expected drop in the diffusion rate during tidal breathing by mixing more fresh air with the increasing amounts of stale air remaining in the respiratory system. The rate of diffusion remains high because the O₂ concentration in the lungs is kept high while the CO₂ levels are kept low.
Defense Mechanisms

Since age changes in the mucus and cilia cause slower movement of mucus, harmful materials such as microbes, particles, and noxious chemicals trapped by the mucus stay in the respiratory system longer. Aging also decreases the functioning of other defense mechanisms, including reflexes (see below), white blood cells, and the immune system. All these age changes cause an increase in the risk of developing respiratory infections and other respiratory problems.

Proper Pressure Changes

Muscles As with most muscles, aging causes respiratory muscles to become weaker. The decrease in muscle strength is not enough to detract from performing tidal breathing or ventilating at moderately increased minute volumes. However, it slowly decreases the maximum pressure changes that the muscles can produce and thus decreases the maximum rate of airflow attainable.

Skeletal System Age changes in the cartilage, bones, and joints of the thorax also reduce a person’s ability to produce large pressure changes in the thoracic cavity. The cartilage attaching the ribs to the sternum becomes more calcified and stiff, and the ribs become less elastic. Age changes in the cartilage and ligaments of other joints, such as those between the ribs and the vertebrae, result in decreases in the ease and range of motion of the bones they connect.

Aging also leads to slight alterations in the positions of the bones of the chest. The chest becomes deeper from front to back, making deep inspiration more difficult. Altered posture from other changes in the skeletal system further reduces a person’s ability to inspire quickly and fully.

Because of these skeletal age changes, there is a decline in the maximum minute volume attainable and an increase in the work of breathing. Older people partially compensate for these effects by relying more on diaphragmatic breathing.

Lungs Though there are no important age changes in the elastic fibers or surfactant, other age changes in the lungs significantly affect pressure changes. For example, aging causes the coiled collagen fibers in the lungs to become somewhat limp and less resilient. Also, aging causes the alveoli to become shallower, and this reduces the amount of surface area present. The resulting reduction in surface tension decreases elastic recoil. Both of these age changes reduce the maximum rate of expiration attainable and add to the work of breathing (Fig. 5.8).

Compliance

Aging causes the coiled collagen fibers to become somewhat limp and stretch more easily. These changes increase the compliance of the lungs and tend to make inspiration easier. Note, however, that the increase in lung compliance is much less than the increase in chest stiffness caused by skeletal age changes. Thus, there is a net increase in stiffness of the respiratory system, resulting in a decreased ability to inspire.

Control Systems

Aging does not seem to affect the contributions of the nervous system to rhythmic breathing under resting conditions. However, three types of age change reduce the ability of the nervous system and endocrine system to cause adaptive changes in ventilation:

1. Neurons monitoring \( \text{O}_2, \text{CO}_2 \), acid/base balance, and muscle activity seem to become less sensitive to changes in these parameters.

FIGURE 5.8 Effects of aging on alveoli: (a) Young alveoli. (b) Old alveoli.
2. There may be changes in the nervous pathways through which all their impulses are sent, resulting in altered ventilation.

3. The lungs become less sensitive to norepinephrine from sympathetic nerves and the endocrine system.

These age changes result in a slower and smaller increase in minute volume when there is a decrease in $O_2$ or an increase in $CO_2$, acids, or body activity. As a result, individuals who begin vigorous activity feel out of breath and tire more quickly as they get older.

Age changes in other parts of the nervous system reduce its ability to provide the swallowing, gag, and cough reflexes that defend the respiratory system (Chap. 6). Because of these changes, it takes a greater amount of material and a longer time to start a defensive reflex. Once it begins, the response is slower and weaker.

Therefore, older individuals must avoid situations that raise the risk of choking. These include eating quickly; talking or laughing while eating; eating while lying on one’s back; and eating after consuming alcoholic beverages or medications that slow the reflexes.

**Consequences**

Reductions in pressure changes caused by weakening of muscles, stiffening of the respiratory system, and decreased alveolar surface area combine with narrowing of the airways to produce two effects. First, they cause a decrease in the rate at which air can flow in the system. Second, they make ventilation more difficult and therefore increase the work of breathing. This reduces the amount of available $O_2$ and increases $CO_2$ in the blood.

Although aging does not change the total lung capacity, age changes affect the volumes of air that can be moved. The more rapid closing of bronchioles, together with stiffening of the system, causes a decrease in both inspiratory and expiratory reserve volume. At the same time, tidal volume increases somewhat, and the age changes cause an increase in residual volume both at rest and during increased ventilation. These changes in volumes cause the vital capacity to decrease.

These changes in respiratory volumes have two effects. First, they further decrease maximum minute volume. Second, the decrease in vital capacity, combined with the increase in residual capacity, means that less fresh inspired air is mixing with more stale air remaining in the lungs. This change decreases the rate of diffusion. The problem is compounded by the increase in dead space. The age-related increase in tidal volume may help compensate for this problem during quiet breathing (Fig. 5.9).

The force of gravity on the lungs causes the lower bronchioles to close sooner than do those in the upper regions. Therefore, the lower parts have a higher proportion of the residual air than do the upper regions. This unevenness in ventilation increases with age. As seen below in the discussion of perfusion and diffusion, this further decreases the efficiency of the system. Thus, as people get older, they must ventilate more air to get the same amount of gas exchange, and this adds to the work of breathing. Breathing more deeply can partially overcome the deleterious effects of uneven ventilation. Aging also reduces the maximum respiratory rate (breaths per minute) because of age changes that slow airflow and age changes in the nervous system.

These decreases in maximum flow rate, maximum volume per breath, and maximum respiratory rate combine to cause a decrease in the maximum minute volume. Many individuals can expect their maximum minute volumes to decline by 50 percent as they pass from their twenties to very old age. This change makes a major contribution to the decrease in the maximum rate of gas exchange as people age. Age changes in perfusion and diffusion, discussed below, cause additional decreases in gas exchange.

**FIGURE 5.9 Age changes in respiratory volumes.**
PERFUSION

Recall from Chap. 4 that perfusion is the passage of blood through the vessels of body structures. Perfusion of the lungs proceeds as follows.

The right atrium receives blood from systemic veins from all parts of the body except the lungs. This blood has little oxygen because the oxygen was removed and used as the blood flowed through capillaries and past body cells. Therefore, this blood is called deoxygenated blood. It also has a high concentration of CO₂, which diffused into the blood from the body cells (Fig. 5.10).

Deoxygenated blood from the right atrium flows into the right ventricle, which then pumps it through the pulmonary arteries to the lungs. As these arteries enter and pass through the lungs, they branch into smaller vessels until they enter the thin-walled pulmonary capillaries. These capillaries carry the blood close to the walls of the
alveoli. This allows gases to diffuse between the blood in the capillaries and the air in the alveoli.

The blood then enters pulmonary veins, which carry blood to the left atrium. Since this blood has a high concentration of $O_2$, it is called oxygenated blood. It also has a low concentration of $CO_2$. This blood will pass from the left atrium into the left ventricle, which will pump it through the systemic arteries to all parts of the body except the lungs.

Like the rate of ventilation, the rate of perfusion must vary as a person’s rate of activity, and therefore the need for gas exchange, varies. Blood flow to an area of the body can be changed by altering the cardiac output and changing the diameter of the arteries delivering blood to body structures.

**DIFFUSION**

Recall that the alveoli are the destinations for inspired air. Their great numbers and deeply curved surfaces provide a great deal of surface area.

The walls of the alveoli are only one cell thick, and the cells are flat and very thin. Thin-walled capillaries surround the alveoli. Only an exceedingly thin noncellular layer (basement membrane) separates the alveolar wall from the capillary wall. These structural features provide a thin surface through which gases must pass. The secretions from some alveolar cells keep their surfaces moist. Thus, the alveoli supply a large, thin, and moist surface that is ideal for the diffusion of gases. Diffusion of $O_2$ and $CO_2$ in the lungs proceeds as follows (Fig. 5.10).

The blood entering the pulmonary capillaries has a very low concentration of $O_2$ and a high concentration of $CO_2$. The air in the alveoli, by contrast, has a high level of $O_2$ and a low level of $CO_2$ because ongoing ventilation continuously refreshes the alveolar air. Therefore, $O_2$ diffuses from the alveolar air into the blood while $CO_2$ diffuses from the blood into the alveolar air.

Much of the $CO_2$ that diffuses into the alveoli is removed with the next ventilation, which also delivers a new supply of $O_2$. Only a very small amount of the $O_2$ that enters the blood can be carried by the plasma. Almost all the oxygen in the blood is bound to hemoglobin molecules, which are contained in the red blood cells. Each hemoglobin molecule can bind up to four molecules of oxygen. When hemoglobin binds oxygen, the result is oxyhemoglobin. Decreased $CO_2$, increased pH, or decreased temperature of the blood increases the amount of oxygen that can be bound to each hemoglobin molecule; the converse is also true. Normally, this promotes complete oxygenation of blood in the lungs, where ventilation keeps $CO_2$ levels and temperature low. It also promotes greater release of oxygen in other capillaries, where body cell activities keep $CO_2$ levels and temperature high. These characteristics of hemoglobin are sometimes displayed as oxyhemoglobin dissociation curves.

Continuous perfusion, coupled with continuous ventilation, keeps diffusion occurring in an uninterrupted fashion. Furthermore, alterations in the rate of ventilation or perfusion can alter the rate of diffusion to meet bodily needs. Increasing ventilation (i.e., minute volume) or perfusion...
increases the differences in concentrations of \(O_2\)
and \(CO_2\) between the blood and alveolar air. These
changes increase the rates of diffusion and gas
exchange. Reducing ventilation or perfusion has
the opposite effects.

**Age Changes in Diffusion**

Aging causes several changes that reduce the
maximum minute volume of ventilation, increase
residual volume, and cause uneven ventilation in
the lungs.

Age changes in the alveoli further decrease the
rate of diffusion. The alveoli become flatter and
shallower, decreasing the amount of surface area.
The alveolar membrane that remains becomes
thicker and undergoes chemical changes which
further impair diffusion (Fig. 5.8).

**EFFECTS FROM ALTERED GAS
EXCHANGE**

**Biological Effects**

In summary, essentially all aspects of the respira-
	ry system involved in gas exchange are detri-

mentally affected by aging, resulting in a drop in
the maximum rate of gas exchange. Furthermore,
there is an overall decline in the efficiency of this
system. Finally, the ability of the respiratory sys-
tem to adjust the rate of gas exchange to meet
body needs declines. These changes occur at a
fairly steady rate throughout life.

As these changes occur, the maximum rate at
which a person can perform physical activities
decreases, and a person who starts a vigorous ac-
tivity such as running or climbing stairs will feel
tired and out of breath sooner as age advances.
Such an individual will not be able to perform at
top speed for an extended period. Age changes
in other systems, including the circulatory, skel-
etal, muscle, and nervous systems, may contrib-
ute to these decrements. The consequences of
these effects can be reduced by raising one’s pace
gradually. Doing this provides extra time for
respiratory functioning to adapt to the increased
need for gas exchange. Also, going at a more mod-
erate pace lowers the required rate of gas exchange.

Although aging causes reductions in several
maximum respiratory values, these age changes
are observed only when people require that the
respiratory system function at maximum capac-
ity. This system has such a great reserve capacity
that the decline in maximum values caused by
aging has essentially no effect on a person who
engages in light or moderately vigorous activi-
ties. Thus, unless a person engages in activities
such as very demanding physical work or highly
competitive athletic events, age changes in respira-
	ry functioning have little noticeable effect on
his or her lifestyle. The aging respiratory system
can provide adequate service in all but the most
physically demanding situations.

Factors other than aging alter gas exchange.
Also, much can be done to minimize age-related
reductions in the ability of the respiratory system
to satisfy the need for gas exchange. For example,
a sedentary lifestyle further limits respiration,
while regular exercise keeps the decline in maxi-
mum minute volume small. Furthermore, incor-
porating adequate vigorous physical activity into
one’s lifestyle can restore much of the decline in
respiratory functioning caused by inactivity.

Another factor that adversely affects respira-
tion is air pollution. Breathing polluted air seems
to increase both the speed and severity of essen-
tially every age change in the respiratory system
mentioned thus far. People who smoke, live in
areas where air quality is poor, or engage in oc-
cupations where the air contains dust, fine par-
ticles, or noxious chemicals have a much faster
and greater loss of respiratory functioning. In
addition, these individuals are at higher risk for
developing respiratory diseases, including lung
cancer, chronic bronchitis, and emphysema. Air
pollutants can injure respiratory cells and tissues
in several ways including physically, chemically,
and through free radicals, microbes and immune
responses. Radon damages lung tissues through
the radiation it causes and the free radicals it in-
duces. Breathing polluted air can be reduced by
avoiding polluted areas; by not smoking; by wear-
ing a protective mask; and by providing adequate
ventilation with clean air in living and working
areas.

**Interactions**

The biological effects of decreased gas exchange
can affect other aspects of life. The nature and
degree of these effects depend on the amount and
importance of physical activity in a person’s life.
Examples of people who may be affected more
dramatically include people whose chief form of
recreation and social contact is competitive sports and people whose jobs involve considerable physical exertion.

Finally, changes in gas exchange can be affected by other types of age changes. For example, upon retirement, a sedentary office worker may take up a physically demanding sport, which may provide the motivation to stop smoking. The result can be a slowing and even a temporary reversal of the decline in respiratory capacity.

DISEASES OF THE RESPIRATORY SYSTEM

While age changes in the respiratory system have only a small impact on the ordinary activities of daily living, changes caused by disease can have a substantial effect. Respiratory diseases reduce a person’s speed and endurance in physical activities and cause significant disability. Treatment can extend for long periods and is often expensive. Furthermore, respiratory system diseases (not including cancer of the lungs) are the fourth leading cause of death for those over age 65. If lung cancer is added, respiratory disease ranks as the third leading cause of death among the elderly.

The reasons for the high incidence of respiratory diseases among older people are similar to those for other diseases. They include reductions in defense mechanisms; more time for the development of slowly progressing diseases; and increases in the number of exposures and the total time of exposure to disease-promoting factors.

There is one factor that contributes to the development of virtually all these diseases: air pollution. One of the most common forms is smoking and inhaling smoke from tobacco products. Though the proportion of smokers in the population has declined, the effects of smoking among older people will be evident for many years because many older people have smoked for long periods. The rate of decline of the respiratory system slows when a person stops smoking and there may even be a period of improvement in gas exchange. However, most effects from long-term smoking are not reversible.

Other forms of air pollution include particulate matter such as dust from coal mining, woodworking, farming, and the manufacture of fabrics. Fumes and vapors such as those from painting, chemical plants, and scientific laboratories can harm the lungs. Smog, automobile fumes, and other types of air pollution associated with urban environments are also significant risk factors for lung damage.

Reducing the inspiration of air pollutants can significantly reduce both the incidence and severity of respiratory disease. Doing this will preserve much of the capacity for gas exchange by the respiratory system.

Respiratory diseases that are most common among people of advancing age include lung cancer, chronic bronchitis, emphysema, pneumonia, and pulmonary embolism. These diseases and two other abnormal conditions (sleep apnea and snoring) will be considered here. In examining these respiratory diseases and abnormal conditions, keep in mind that the ability of hemoglobin to bind oxygen is affected by CO₂, pH, and temperature. Respiratory diseases and conditions can reduce ventilation, leaving more CO₂ in the blood and more warm air in the lungs. These changes reduce the ability to oxygenate blood not only because the O₂ supply to the lungs is reduced. The elevated CO₂ reduces the pH in blood in the lungs, and the blood remains somewhat warmer. Under these conditions, the hemoglobin in blood passing through the lungs cannot pick up and hold as much oxygen. Therefore, the hemoglobin cannot transport as much O₂ to body cells.

Lung Cancer

Normally, cells reproduce when the body needs more of them; once the need is met, they stop reproducing. An example is the temporary rapid reproduction of skin cells that occurs until a cut in the skin heals. Cancer consists of cells that continue to divide and spread out in an uncontrolled fashion even when they are not needed. A clump of these cells is called a tumor.

Some forms of cancer develop from lung cells and are called primary lung cancer. These are the types caused primarily by smoking. Many other cancers of the lungs develop when the circulatory system moves cancer cells from another place in the body to the lungs. Cancer that moves to another part of the body is called metastatic cancer. Metastatic lung cancer often comes from the breasts or the reproductive system.

A person with lung cancer may have from one tumor to very many tumors. Whether the cancer is primary or metastatic, the effects on the lungs are similar. Ventilation becomes more difficult
because airways get blocked when tumors grow inside them or squeeze them closed. Air volumes are reduced as alveoli become filled with cancer cells. Occasionally the cancer becomes so large or stiffens the lungs so much that they cannot inflate or deflate adequately for ventilation. Cancer cells in the alveoli may reduce diffusion by thickening or replacing the respiratory membrane between the air and the blood. Sometimes cancer will distort, squeeze, or replace the pulmonary vessels so that perfusion is reduced. Some blood vessels are weakened, causing bleeding.

Several warning signs indicate that lung cancer may be present. They include a persistent cough, coughing or spitting up blood, pain in the chest, difficulty swallowing, hoarseness, easy fatigability and the feeling of breathlessness, and a swelling of the fingertips. Any of these indicators warrant evaluation by a physician.

Though some forms of lung cancer can be cured if discovered early enough, most cases are not identified until the cancer has grown so much that it cannot be eliminated. The vast majority of cases of lung cancer result in death within a few years. The only effective “cure” is prevention: avoiding tobacco smoke and other forms of air pollution.

Chronic Bronchitis

To understand chronic bronchitis, recall that the trachea and bronchi are lined with a thin layer of mucus and that as the mucus is made, cilia sweep it up and out of the airways.

Development If a person inspires air with an excess amount of harmful particles or noxious chemicals, the cells lining the trachea and bronchi become injured. The resulting inflammation causes those cells to make mucus much faster, and the lining of the airways becomes swollen. In addition, the beating of cilia slows. The person now has bronchitis and will begin to cough to remove the extra mucus and pollutants.

If this person breathes the pollutants frequently and continuously, the airways remain inflamed for a longer time, and the person then has chronic bronchitis. This condition is accompanied by extra mucus production and coughing. After a while the cilia will be damaged and may completely disappear.

Effects The major effect of chronic bronchitis is to reduce ventilation by making the airways narrow in two ways. First, mucus accumulates because it is being produced more quickly and removed more slowly. Second, the lining of the airways swells inwardly. The effect on airflow through the trachea and bronchi is similar to the stuffed-up feeling that occurs when a head cold causes swelling and the accumulation of mucus in nasal passages.

Expiration becomes especially difficult because the lower airways normally narrow during expiration. The additional narrowing from the mucus and swelling makes them so narrow that expiration can occur only very slowly. This decreases the minute volume, and so having enough gas exchange to meet the body’s needs is quite difficult. The problem is compounded because the person will begin to rely more on forced expiration, increasing the work of breathing. The effort used in coughing raises the work of breathing to levels that may leave the victim dizzy, breathless, and temporarily incapacitated.

The problem becomes very serious when the person tries to do something physically active. Fatigue and the sense of being out of breath develop quickly and are rather severe. Some individuals are disabled by this disease.

Fortunately, many cases of chronic bronchitis that have not been allowed to progress too long can be cured. The person need only eliminate breathing polluted air. Eventually, mucus production will slow and the cilia will grow back and begin to function as before.

Curing chronic bronchitis can be difficult if smoking is the source of the air pollution, however, because tobacco smoke contains addictive chemicals such as nicotine. Also, as the respiratory system begins to clear itself, coughing increases temporarily. Smokers often experience extra coughing in the morning because the clearing action began during the night, when they were not smoking. After a period of abstention, smoking seems to help because it relieves the withdrawal symptoms and stops the clearing action, and thus stops the coughing. Of course, continuing to smoke only relieves certain symptoms while the disease continues to destroy the person’s respiratory system.

Besides reducing directly the performance of the respiratory system, chronic bronchitis increases the risk of infection of the respiratory system because the accumulation and slow removal of mucus allow microbes to flourish in the air-
ways. It can also lead to emphysema, and the chronic coughing contributes to hemorrhoids. Long-term smoking is also a major risk factor for nonrespiratory diseases such as heart attack, atherosclerosis, and stroke.

**Emphysema**

*Emphysema* is a disease that involves actual destruction of some parts of the lungs. There are two main forms: *centrilobular emphysema* (CLE) and *panlobar emphysema* (PLE). Both types will be present in most people with emphysema, though one type will predominate.

**Centrilobar Emphysema** Centrilobar emphysema most often develops along with or after chronic bronchitis. It involves a thinning and weakening of the smallest bronchioles and the production of much mucus. Many results are similar to those of chronic bronchitis. Additionally, the damage to the bronchioles usually results in a decrease in the number of small blood vessels in the lungs, decreasing perfusion. The reduction in blood vessels also makes it harder for the heart to pump blood through the lungs, and the overworked heart eventually becomes weaker. If CLE continues to progress, the victim eventually dies of respiratory failure, respiratory infection, or heart failure.

**Panlobar Emphysema** Panlobar emphysema is less common than CLE. Though the major cause is air pollution, some people inherit a tendency to develop this type of emphysema.

PLE causes destruction of the walls of the alveoli and alveolar sacs. The results are like a highly exaggerated version of age changes in the alveoli. Many walls between the alveoli shrink and disappear. Neighboring alveoli blend to form large air-filled spaces. The lungs change from having microscopic spaces like those found in Styrofoam to having large spaces like those in a sponge. The wall material that remains is weaker and less elastic. All these changes reduce ventilation.

With PLE, expiration becomes more difficult and more residual air is left in the lungs. As passive expiration decreases, forced expiration increases, increasing the work of breathing. Perfusion also decreases because the number of capillaries declines as the alveolar walls are destroyed. Besides reducing gas exchange, this overworks the heart, occasionally leading to heart failure. Finally, diffusion is reduced because there is a decrease in the amount of surface area.

A complication of PLE is the partial or complete collapse of a lung. This occurs when a hollow space developing close to the lung surface bursts like a bubble. As escaping air separates the lung from the thoracic wall, the lung collapses like a balloon with a small leak. This condition is called *pneumothorax*. Proper inspiration is impossible unless the leak heals and the body absorbs the air from the thoracic cavity.

**Overall Effects of Emphysema** People in the early stages of emphysema may hardly notice the decline in their ability to perform physical activities. As the disease progresses and devastates more of the lungs, gas exchange plummets. Eventually, even walking at an ordinary pace becomes a challenge. Individuals with advanced cases are so disabled that they may be unable to get up, sit up, or even roll over in bed without extreme fatigue. Mild exertion or a slight respiratory infection can cause death. Among people over age 55, emphysema is the fifth leading cause of death for men and the seventh leading cause for women.

**Pneumonia**

*Pneumonia* is actually a group of related diseases involving inflammation in the lungs. Several types reduce a person's ability to inspire. Older people are especially affected by pneumonia caused by microbes (bacteria, viruses, and fungi) and by dust and chemical vapors. Pneumonia can also result from aspirating stomach contents that have moved up into the throat.

**Microbial Pneumonia** Reasons for the age-related increased susceptibility to microbial pneumonia include age changes in the functioning of the mucociliary escalator, white blood cells, and the immune system; the rising prevalence of chronic bronchitis and emphysema; and other diseases that weaken the body and make it less able to ward off infections.

Pneumonia caused by bacteria results in filling of the airways and alveoli with fluids and cells from their walls. This material blocks the airways. It usually becomes somewhat solid after 1 to 2 days. If a person is otherwise healthy and receives proper treatment, such as antibiotics, the
infection can be overcome and the material will be cleared away after about a week.

Many types of bacteria that cause pneumonia leave the lungs with no residual damage. However, some forms cause serious and permanent damage that results in a reduction in respiratory functioning and can cause death. These forms are the ones most likely to occur in weakened or hospitalized individuals.

Viral pneumonia affects the walls of the alveoli, causing them to accumulate fluids and become thicker, reducing gas exchange. If a person is healthy and has a good immune system, the immune response will eliminate the virus in a few days and the lungs will return to normal functioning.

Because fungal pneumonia and tuberculosis cause death of the portions of the lungs they infect, they can be more serious than bacterial or viral pneumonia. Thus, after fungal and tubercular infections are stopped, the lungs are left with regions that no longer function. Areas affected by tuberculosis are filled in with solid scar tissue which, if calcified, can be detected on x-ray. If enough areas of the lungs are destroyed, gas exchange and activity levels are permanently reduced. More extensive damage results in death.

Unfortunately, many older individuals are not healthy and do not have strong immune systems when they get pneumonia. Weakened persons may have great difficulty combating the infection. Then the disease lasts longer and has a greater impact on the respiratory system. The proportion of individuals who survive microbial pneumonia decreases rapidly with age. Those who survive are often left weakened for long periods.

Dust and Vapors Some individuals breathe large amounts of certain types of air pollution repeatedly for long periods, usually because of their occupations. Examples include farmers, miners, textile mill workers, sandblasters, and woodworkers. The heavy exposure and the size and chemical nature of such air pollutants cause the lungs to form large quantities of fibers and develop the condition called pulmonary fibrosis.

With pulmonary fibrosis, the normal amount and rate of age changes in the lungs increase dramatically, leading to a rapid decline in gas exchange. Very severely affected people will become quite disabled. Since the fibrosis is permanent, affected individuals can recover little if any of the lost respiratory functioning even if they avoid future exposure to air pollution. The only solution is to prevent pulmonary fibrosis by avoiding its causes.

Pulmonary Embolism

Pulmonary embolism (Chap. 4) is a disease condition in which blood clots have moved to the lungs from the systemic veins or the heart. Conditions commonly promoting the formation of such emboli in the elderly include varicose veins, congestive heart failure, and immobility. The elderly are especially prone to having conditions that cause immobility. These include heart attack, stroke, hospitalization, recovery from surgery, and fractures. The effects of pulmonary embolism depend on the size and number of pulmonary emboli.

Control Errors

Two age changes involving the control of ventilation that have not yet been discussed are sleep apnea and snoring.

Sleep Apnea Sleep apnea (SA) means having at least five temporary cessations of ventilation per hour or exhibiting at least 10 occasions of depressed ventilation and cessation of ventilation per hour when asleep. The incidence of sleep apnea increases with age up to age 65, after which the incidence plateaus. It is present in 4 percent of younger adults but in 25 percent to 30 percent of people over age 64. The male:female ratio for SA is approximately 3:1.

Sleep apnea may be caused by narrowing and collapsing of the pharynx, especially when in a supine position (i.e., sleeping on one's back); because the respiratory center becomes less sensitive; or because the center simply stops initiating inspiration. Then blood levels of O2 and CO2 change. These alterations in the blood may provide the necessary stimulation to begin inspiration again. People with sleep apnea tend to snore and to have frequent sudden awakenings with feelings of respiratory distress.

Mild sleep apnea seems to have no deleterious affect on the body. However, frequent awakenings can lead to fatigue, indications of sleep deprivation, and adverse alterations in mood and person-
ality. Because sleep apnea causes significant fluctuations in $O_2$, $CO_2$, and blood pressure, serious cases increase the risk of heart attack and stroke. Treatments for SA include avoiding sleeping in a supine position; using masks with pumps that provide positive pressure into the respiratory system; reversal of obesity; medications; and surgical correction of the pharyngeal region.

**Snoring**  
Snoring, or making loud breathing sounds when asleep, is due to partially obstructed upper airways. Approximately half of all women and well over half of all men above age 65 snore. Some individuals who snore also have sleep apnea.

Snoring causes a variety of problems. Biologically, it causes from mild to severe adverse effects on blood $O_2$ and $CO_2$ levels and on circulation. It can also contribute to high blood pressure and heart disease. Since snoring disrupts normal sleep patterns even if the person who is snoring does not awaken, it can result in fatigue and other indications of sleep deprivation.

Anyone who sleeps near a person who snores can attest to some of the social implications. Their responses to the person who snores, together with the multitude of jokes about snoring, can add to the psychological impact produced by sleep deprivation. The fatigue felt by many snorers also affects their social interactions and can impinge on their ability to carry out their jobs.

Though the causes of snoring and the role of the nervous system in snoring are not clear, research has provided methods of treatment for this condition.

**SMOKING**

Main consequences in the respiratory system from smoking have been mentioned. Smoking has adverse effects in other areas of the body, also. In general, smoking increases the formation of free radicals and lipid peroxides while reducing the antioxidant actions of vitamin C, vitamin E, and $\beta$-carotenes. Smoking may increase free radical damage to DNA by 50 percent. In the skin, smoking speeds up and amplifies the effects from aging and from photoaging. Smoking is associated with increased risks for most skin cancers. In the circulatory system, smoking damages the endothelium; raises blood pressure; and increases substantially the risk of blood clots, of atherosclerosis, and of their complications. Effects on these two systems are due partly to constriction of skin vessels and reductions in blood oxygen caused by smoking. These two changes develop within minutes of initiating smoking and can last for hours, long enough to light the next cigarette. The result is continuous inadequate blood flow in the skin and elevated blood pressure. In the eyes, smoking is associated with a higher incidence of cataracts and diseases of the retina. Smoking reduces estrogen levels in women and speeds up age-related thinning of bones. Smoking doubles the problems from non-insulin dependent diabetes; suppresses normal functioning of the immune system; promotes autoimmune diseases; and is associated with higher rates of reproductive system and digestive system cancers. Cessation of smoking is associated with reduction or complete reversal of these problems and risks.

**SOUND PRODUCTION AND SPEECH**

The vocalizations produced by people involve words and a variety of other sounds, such as moans, grunts, whistles, cheers, and laughing. People use sound production for communication. Communication among individuals by sound and other means (e.g., visual signals) is important to a high quality of life and to survival because it is one of the three components in negative feedback systems. A common example of using vocalization as part of a negative feedback system is shouting a warning to a person in danger.

Human sound production can enhance life in other ways. Words and other vocalizations can motivate and encourage positive actions such as beginning a new career or hobby. They are also used in teaching, praising, consoling, expressing emotions, and many other human activities. And what of the beauty of a poem or song? All these are created by the sounds produced by the flow of air through airways.

**Mechanisms**

The respiratory system produces sound by passing air through the upper airways and the mouth. Most of the sound people make is caused when air passing through the larynx causes the vibration of two flaps of tissue called the vocal cords (Fig. 5.5). The sound gets louder when more air flows through the larynx.
Different muscle contractions in the larynx control the position and tension of the vocal cords and thus alter the pitch of sounds. The sounds made by the vocal cords are modified by the other upper airways, especially the nasal passages and the mouth. By changing the shape of these passages and moving the tongue, a person can create a multitude of sounds and form words.

All the actions that produce and modify sounds from the respiratory system are controlled by the nervous system.

**Age Changes**

Many age changes that alter inspiration and especially those which modify expiration affect sound production. Age-related stiffening of the larynx, shrinkage of the vocal cords and its muscles, and changes in the mouth are also important. Age changes in the nervous system are also important since sound production depends on the coordinated action of many muscles. Even age changes in hearing are important because the ears provide feedback information so that the sounds a person produces can be adjusted to conform to the sounds intended by that person.

Because of age changes in these areas, the voice becomes more variable in pitch and volume during speaking. Female voices often become lower in pitch, while male voices often become higher in pitch. Other common changes include increases in hoarseness, roughness, and extraneous sounds while speaking. The voice often becomes weaker, and elders have declining abilities to speak very quietly or with very loud volume. The ability to control volume declines, and the precision of word pronunciation diminishes.

Language fluency and vocabulary usually do not decline, and often increase. However, phrases and sentences often become shorter, syllables and words are repeated more often, and more words are pronounced incompletely. These trends in speaking become more prominent in stressful situations. Of course, variability among elders increases with age, and some elders retain the voice and speech of a young adult.

All these changes reduce the effectiveness of vocalization in providing communication. Additionally, some of the pleasure derived from the human voice may be lost. As a result, the contribution of the voice to happy and healthy survival diminishes. Age changes in the voice also alter the way people respond socially to individuals who are getting older. These changes in turn affect aging individuals' responses and self-images. Therefore, biological aging of vocalization can influence nonbiological aspects of life.